Structural Instrumentation and Monitoring

Navigation Lock and Dam Inspection and Emergency Repairs Workshop

19 April 2006

Bruce Barker
Information Technology Laboratory, ERDC

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ny Instrument Civil Works Structures

- As directed by COE regulations and guidance
  - EM 1110-2-4300, Engineering and Design - Instrumentation for Concrete Structures
  - ER 1110-2-103 Strong Motion Earthquake Monitoring
- Ensure life-cycle performance of critical structures
- Support preventive and predictive maintenance programs for key components
- Establish nominal conditions and loads
- Provide real-time information or alerts in extreme events or conditions
- Replace lost manpower with

Then Why Don't We?

- The need for instrumentation is seldom recognized…until there is a problem
- $$$ - Both from an installation and maintenance standpoint
- Lack of maintenance programs for systems can result in poor long-term reliability
- Difficult to retrofit existing infrastructure
- Bad experiences with data management – over sampling, and lack of automated analysis
- Lack of awareness of new technologies that can minimize the above

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Sensors and Measurement Options Available

- Pore Pressures (Piezometers, Pressure cells)
- Fluid Velocities (Flow meters)
- Displacements (Extensometers, LVDT's, strain and crack gages)
- Movement (GPS Systems and DGPS)
- Orientation Angle & Tilt (Inclinometers, Tilt meters)
- Dynamic Motions (Accelerometers, Geophones, Seismographs)

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Examples of Structural Instrumentation Projects

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Trunnion Anchorage Testing Sep – Nov 2005

John Redmond Dam

Canton Dam

Fall River Dam

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Trunnion Anchorage Testing Sep – Nov 2005

(Tulsa District)

Rust Stains indicate possible corrosion of anchor beams

The district was concerned that corrosion of the trunion anchorage beams may have significantly weakened the gate support structure.

A method was needed to test the condition of the beams

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Trunnion Anchor Testing - Canton Dam

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Trunnion Anchor Testing – Canton Dam

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Canton Dam Trunnion Anchor Testing

Strain Gage Assembly Bolted to I-Beam

Strain Gage Location

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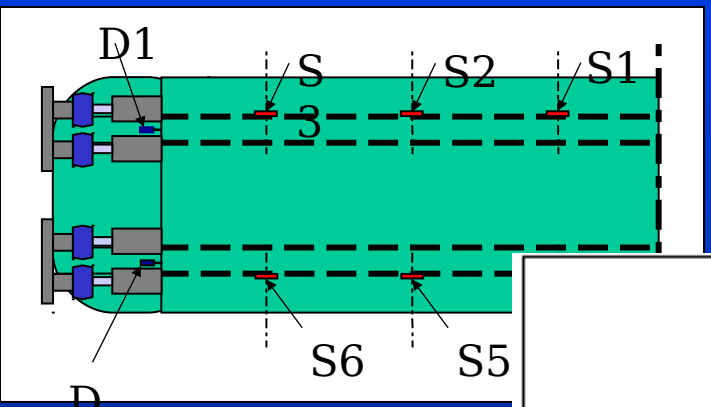
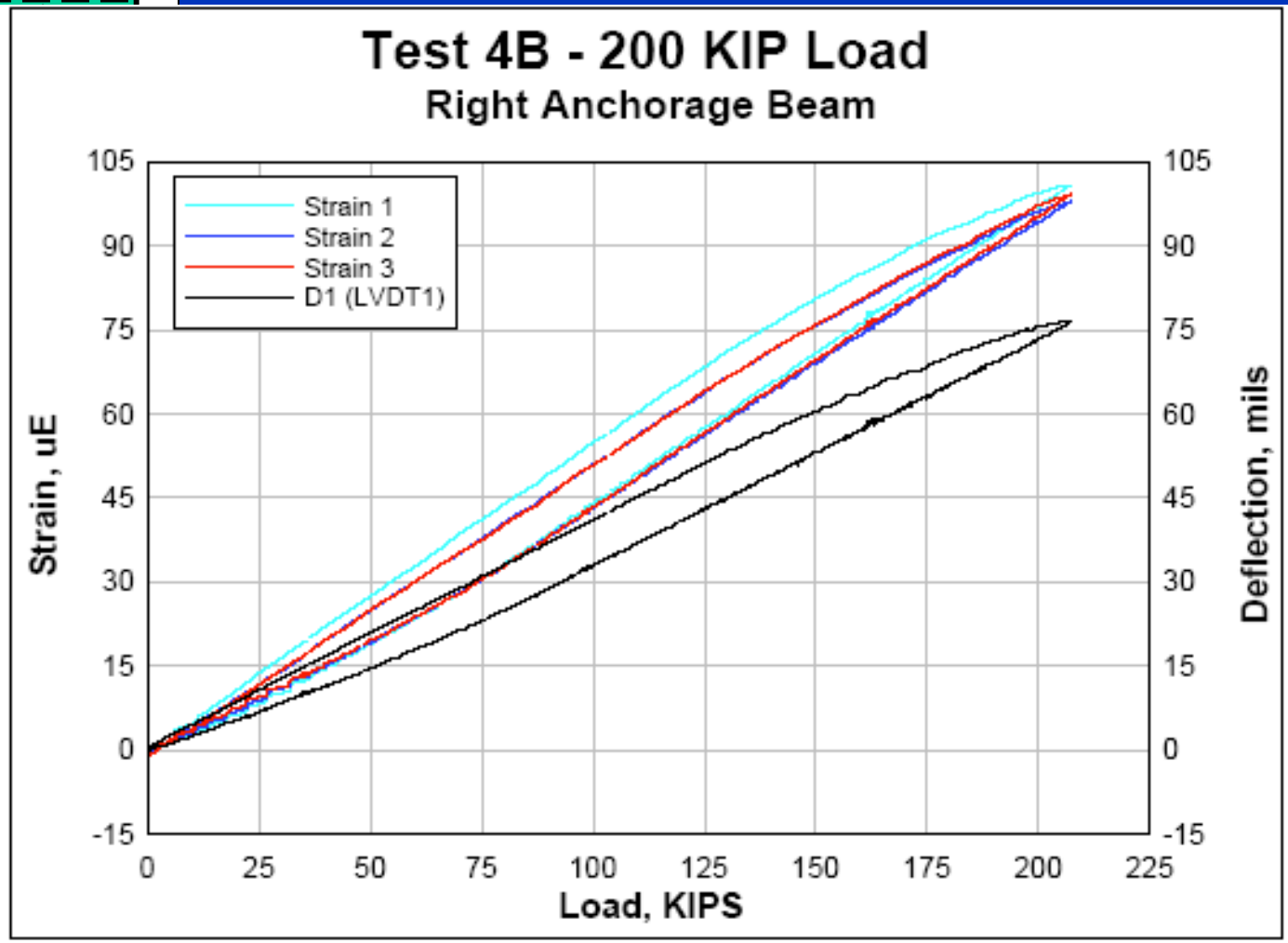
Canton Dam - Pier 15 Data



Gage Locations



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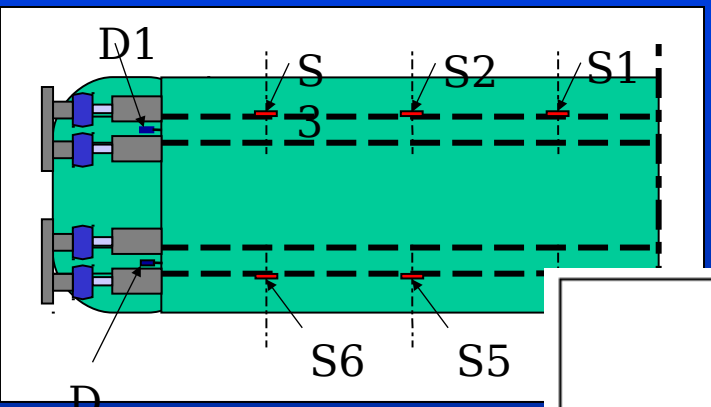
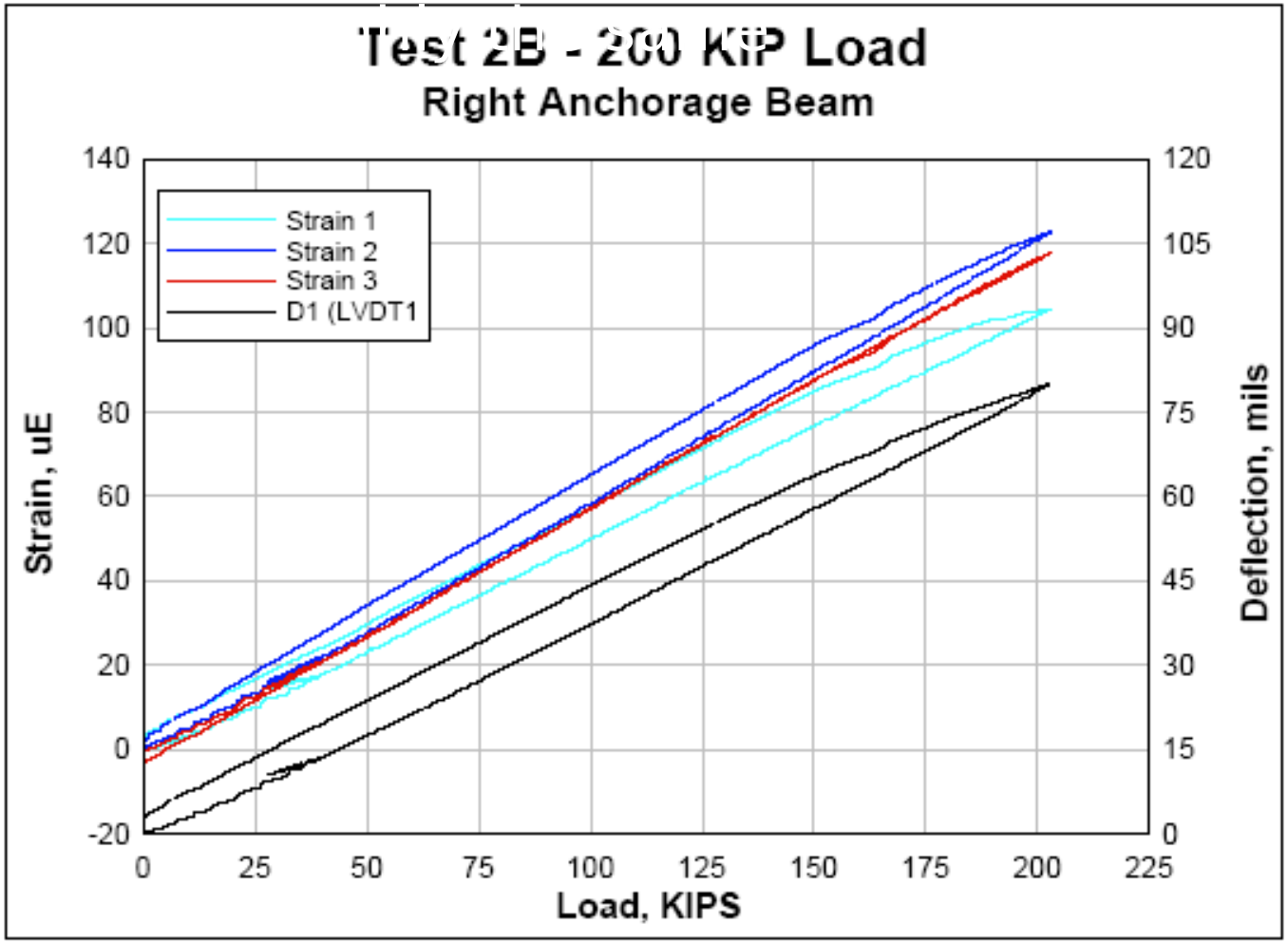
Canton Dam - Pier 16 Data



Gage Locations

The expectation was that Pier 16 would test “weaker” than Pier 15 – Results were



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Long-term Monitoring Instrumentation Installed at John Redmond Dam

Weldable Strain Trans- ducers were attached to gate girders

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Long-term Monitoring Instrumentation Installed at John Redmond Dam

LVDT Installed on Anchorage Girder

CR-1000 Datalogger with cellular interface

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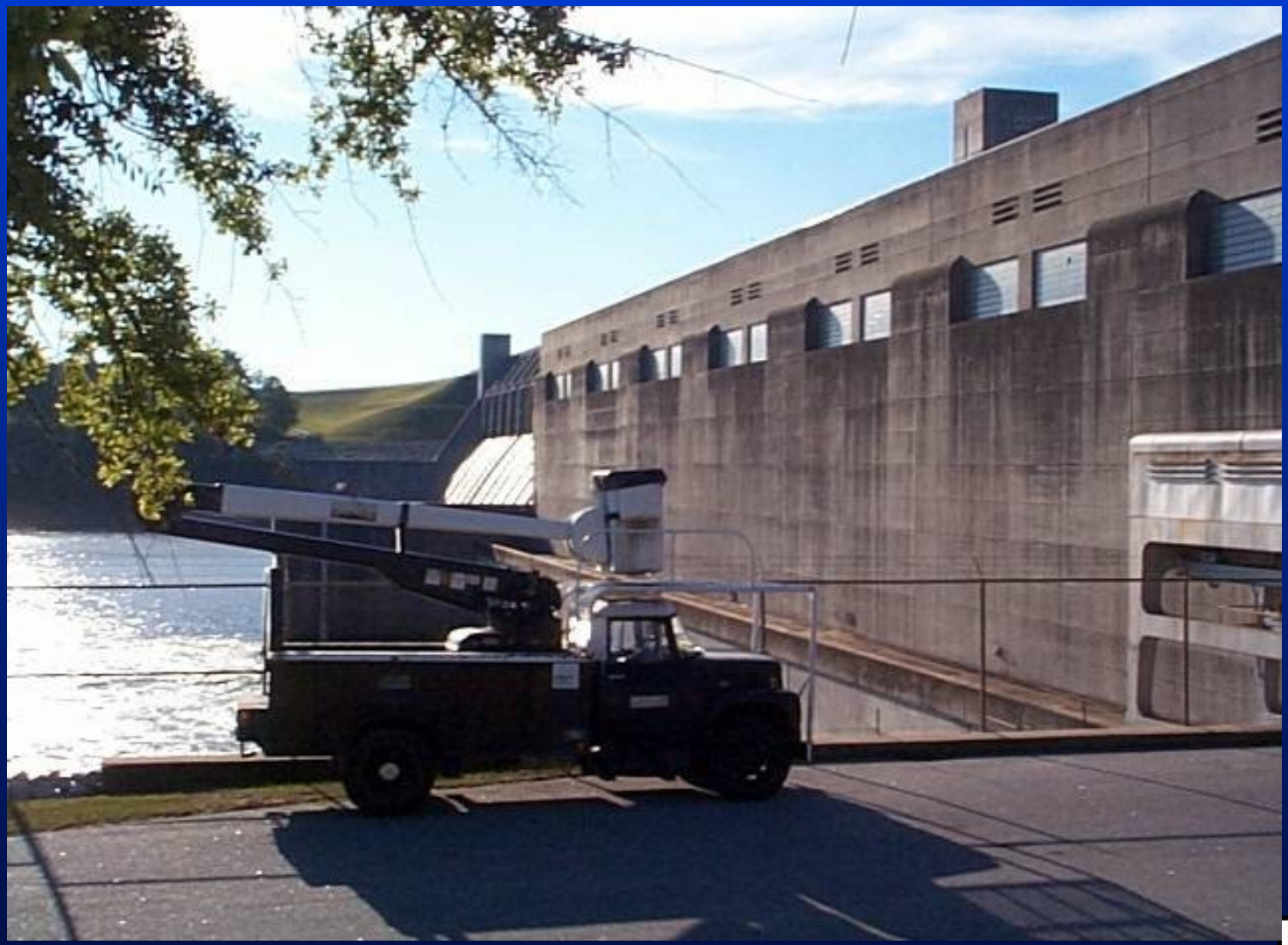
Trunnion Friction Evaluation at Strom Thurmond Dam, GA (Savannah District)



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Trunnion Friction Measurement Concept

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Trunnion Friction Evaluation at Strom Thurmond Dam, GA (Savannah District)

LASER TARGETS

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Greenup L&D Miter Gate Instrumentation, (Huntington District) Sep- Nov 2003

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Greenup L&D Miter Gate

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Damage Found:
Cracking at Reinforcement Guss

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Damage to Reinforcement Flanging

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Cracking Around the Pintle Casting

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Cracking Around the Pintle Casting

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Out of plane deformation of the thrust diaphragm

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Miter Gate Repairs

- Remove triangular gussets and replace with round gussets
- Remove and replace cracked flanges
- Heat straighten out-of-plane distortion of thrust diaphragm and girder web
- Add stiffeners to thrust diaphragm and girder web
- Reset quoin block
- Install long term monitoring instrumentation to help understand the source.

Return lock to service as soon as possible!

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Gate Instrumentation - Strain Gage Locations

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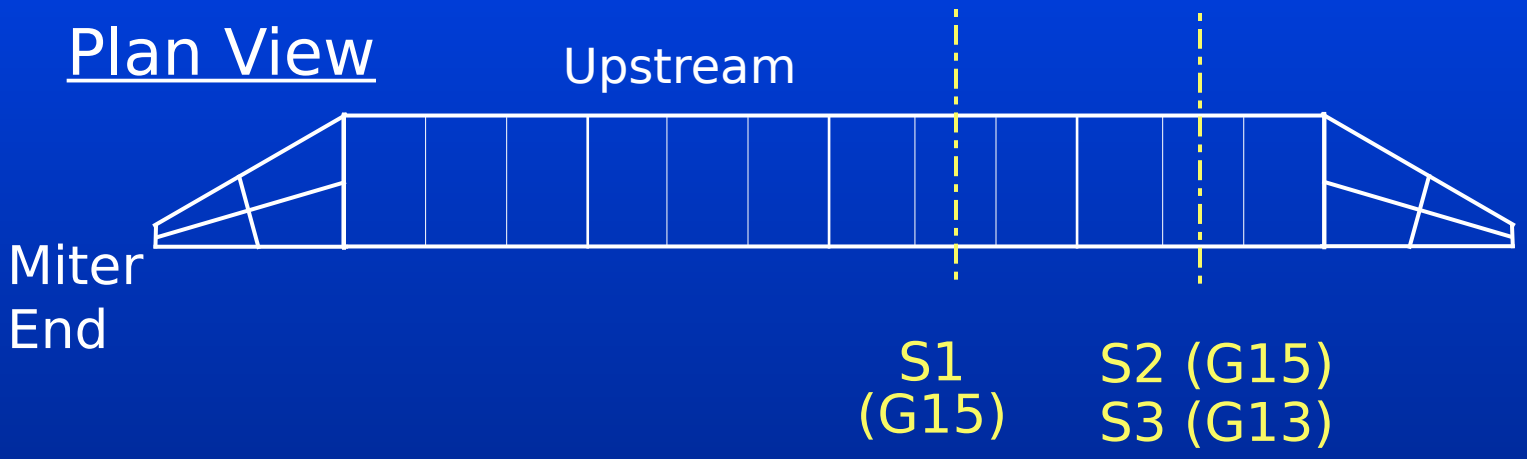
Strain Gage Locations

Plan View



Section

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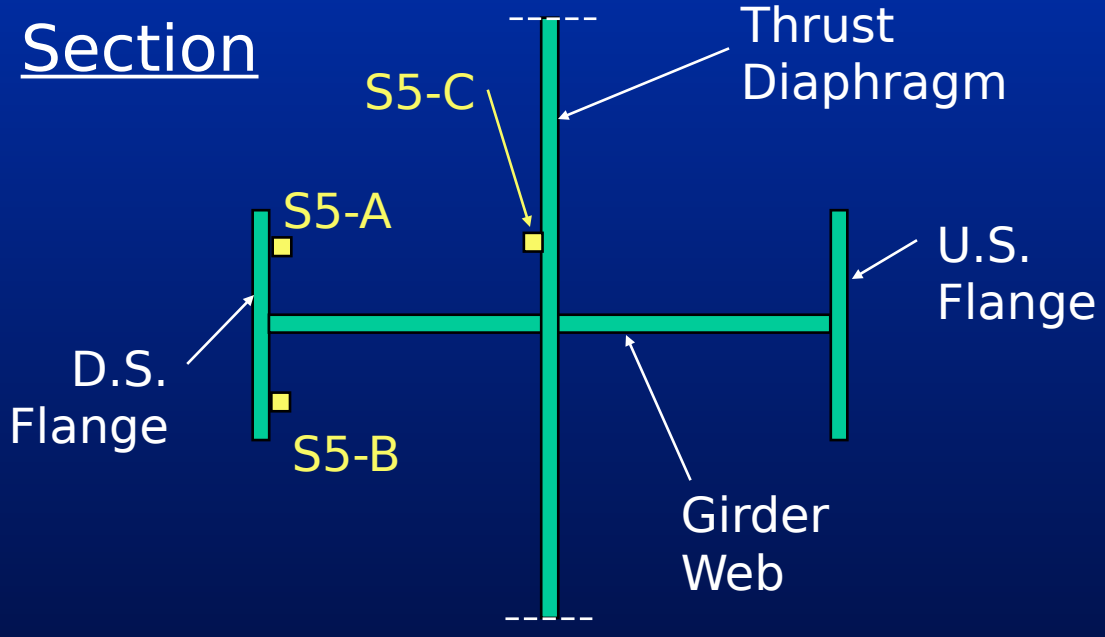
Strain Gage Locations

Plan View

Section



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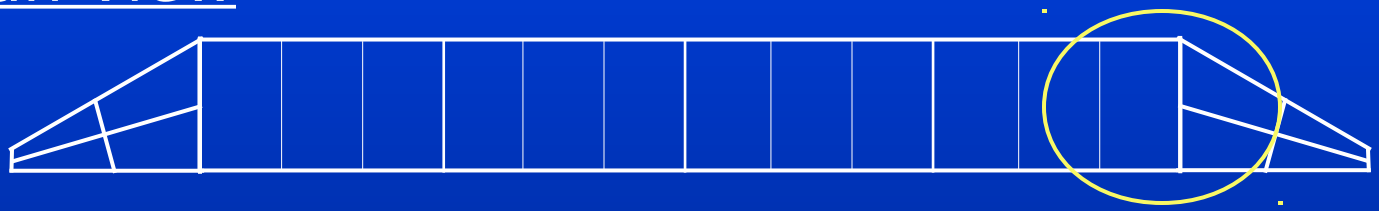
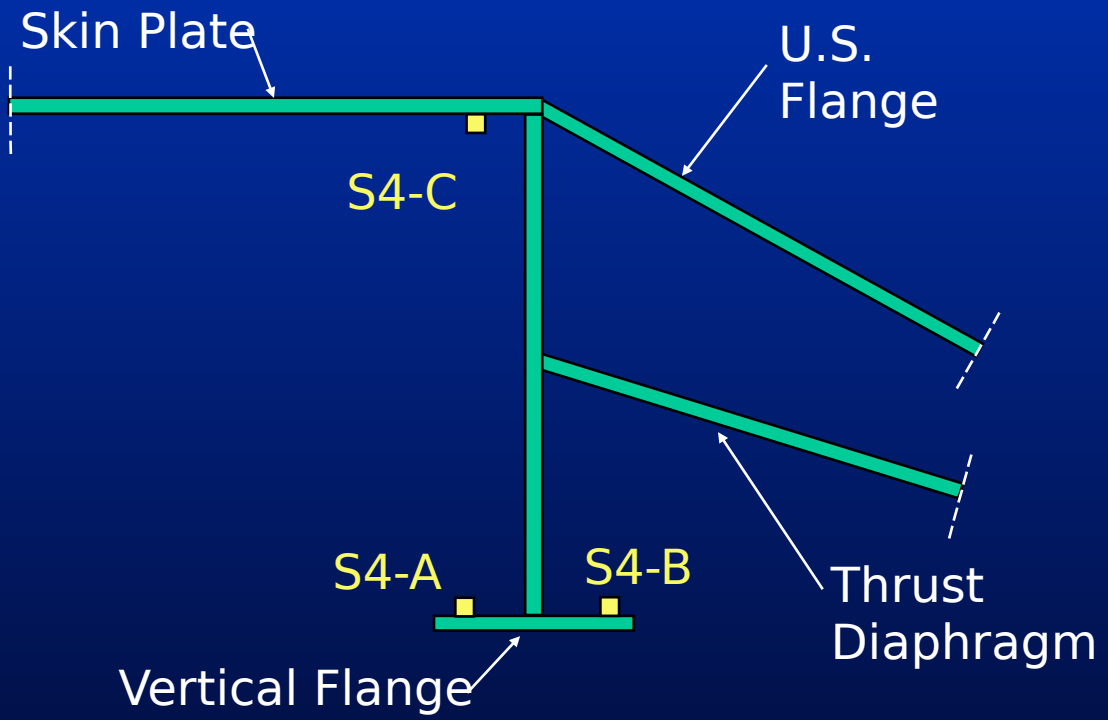
Strain Gage Locations

Plan View



Miter End

Detail



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Strain Gage Installation

HiTech Products Strain Sensor

ERDC technician Tommy Carr welding down a strain gage

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Cable Protection

Cable protection was done with flex tubing and a 1-1/2” conduit run from the top of the gate to the bottom

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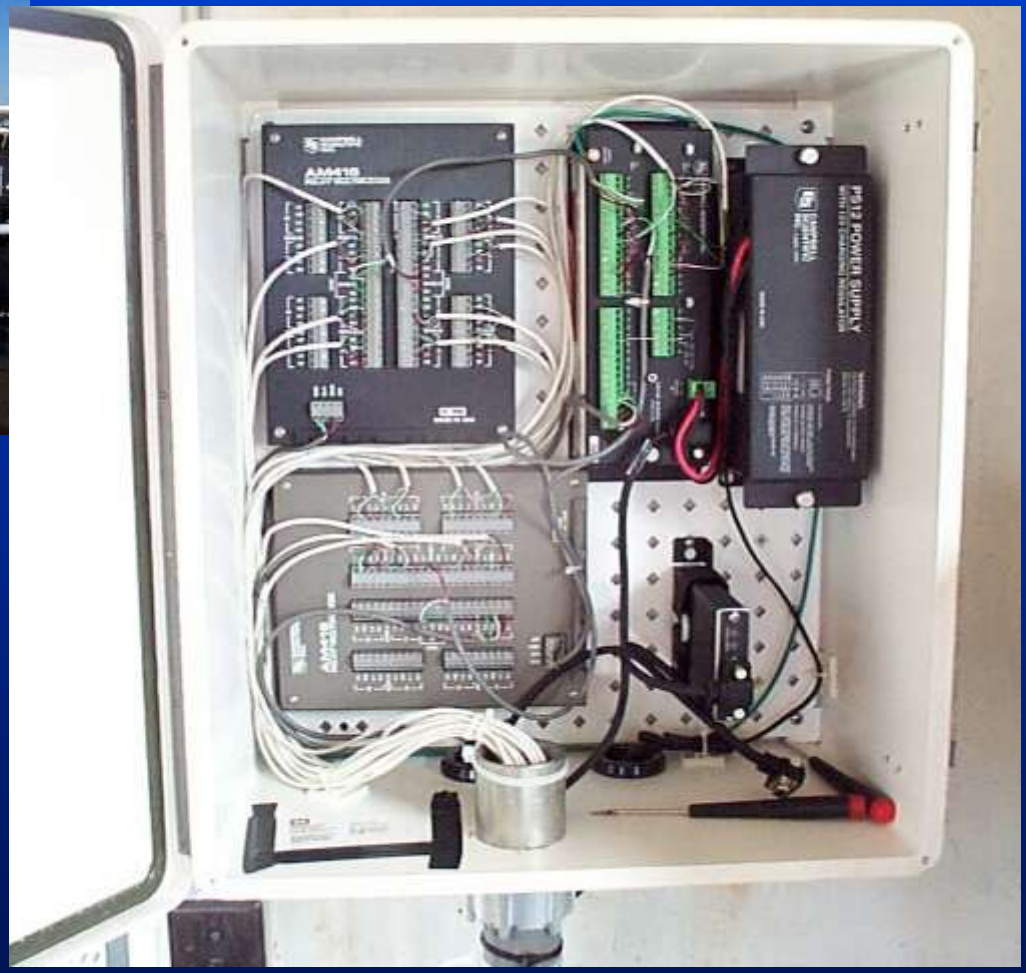
Data Collection



Campbell Scientific CR10X Data logger Installed in gate control building

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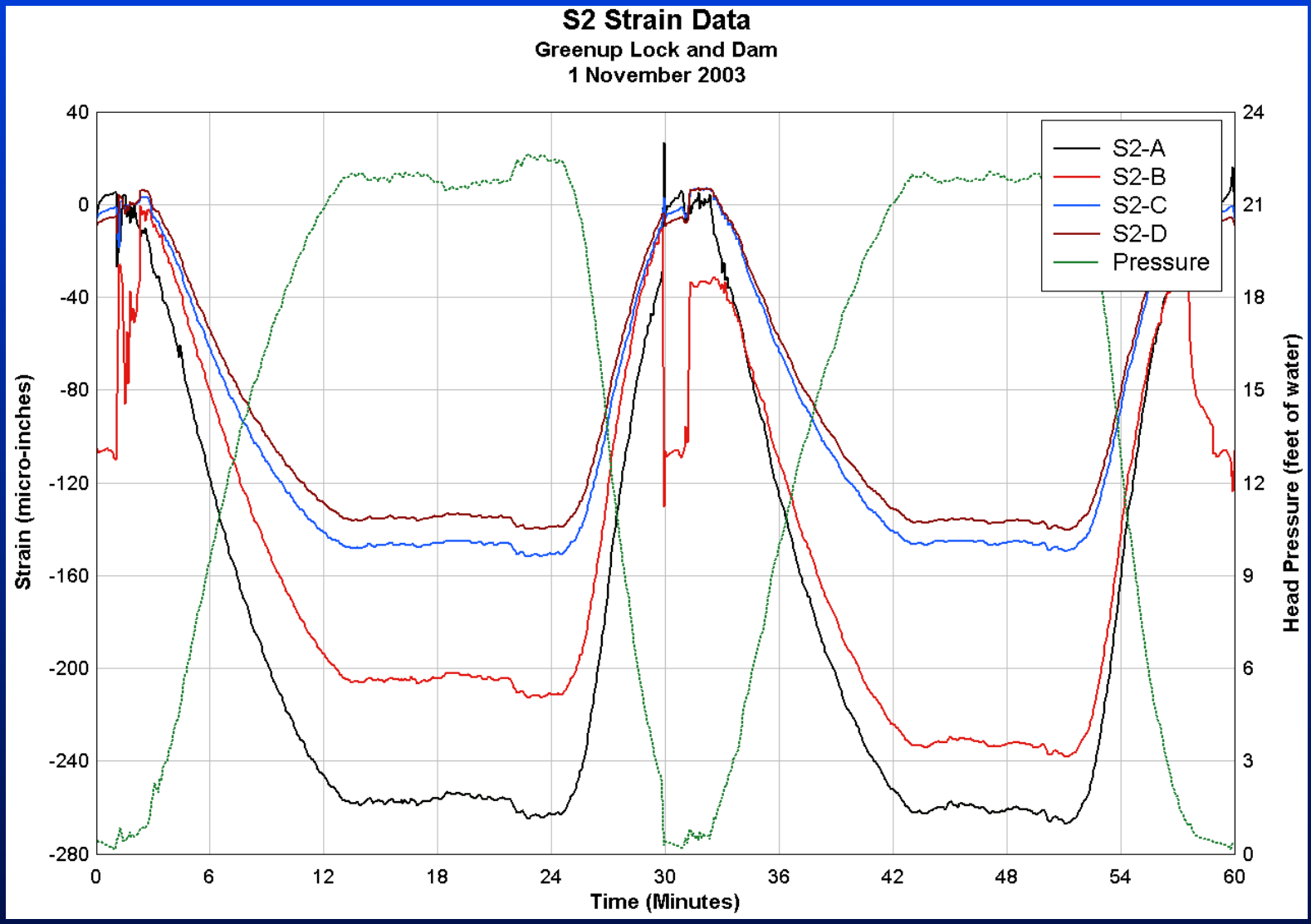
Strain Data – S2 Gages



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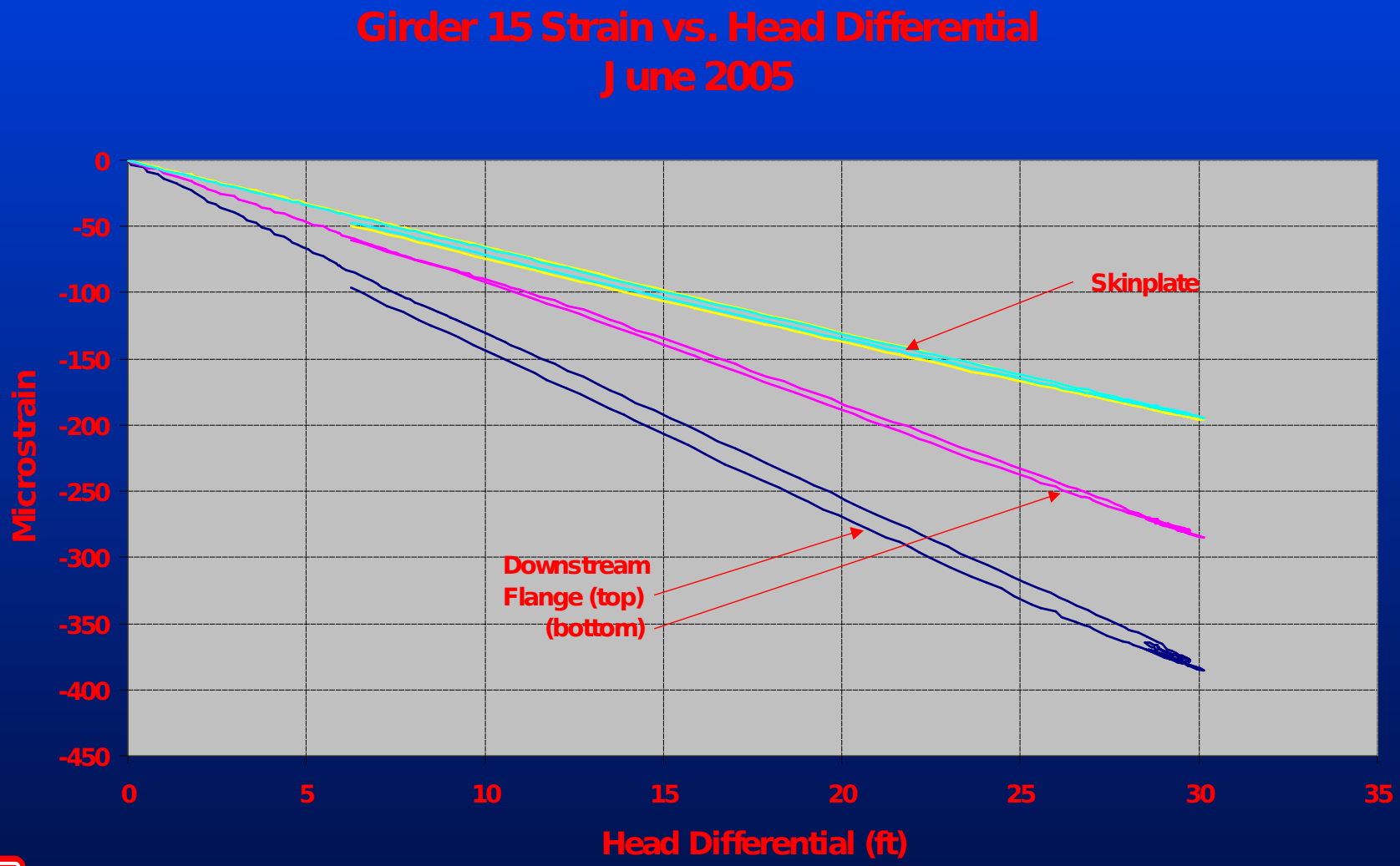
Greenup L&D Miter Gate



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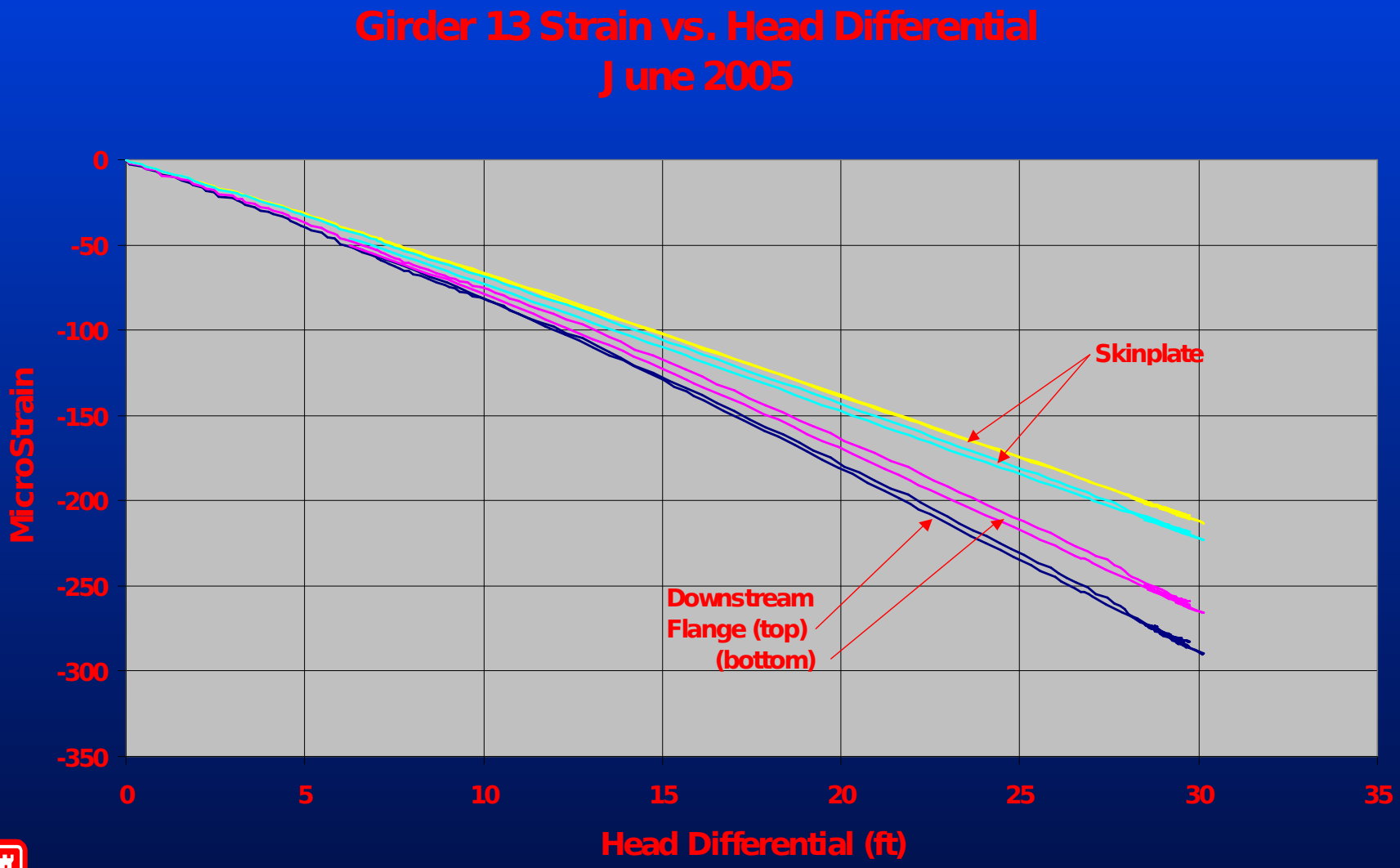
Greenup L&D Miter Gate



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Example of a Geotechnical Instrumentation Project

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Carters Reregulation Dam – Expansive Concrete AAR (Mobile District)

Crack at South Abutment

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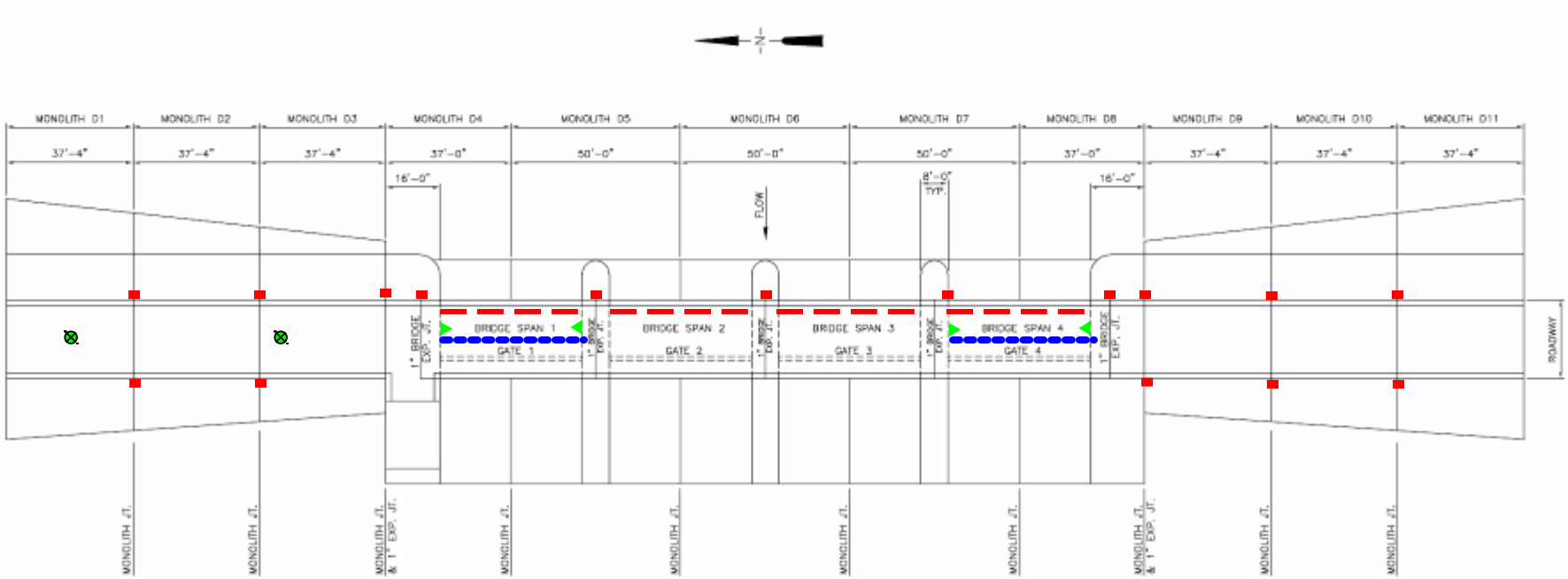
22 Jan 2005

CARTERS REREGULATION DAM PROPOSED INTRUMENTATION LOCATIONS



REREGULATION DAM PLAN

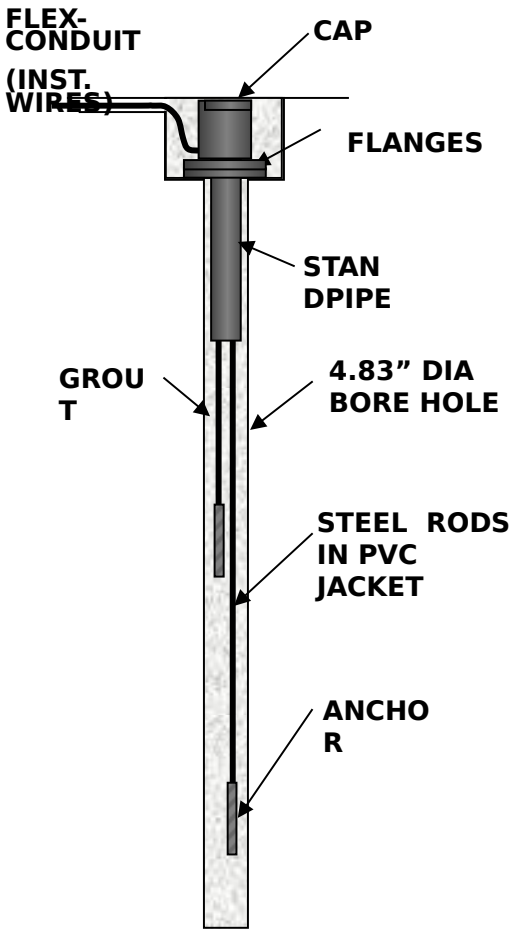
LEGEND

- LVDT / GAUGE BLOCK
- TILT-METER
- BOREHOLE EXTENSOMETER
- STRING POTENTIOMETER
- HORIZONTAL EXTENSOMETER

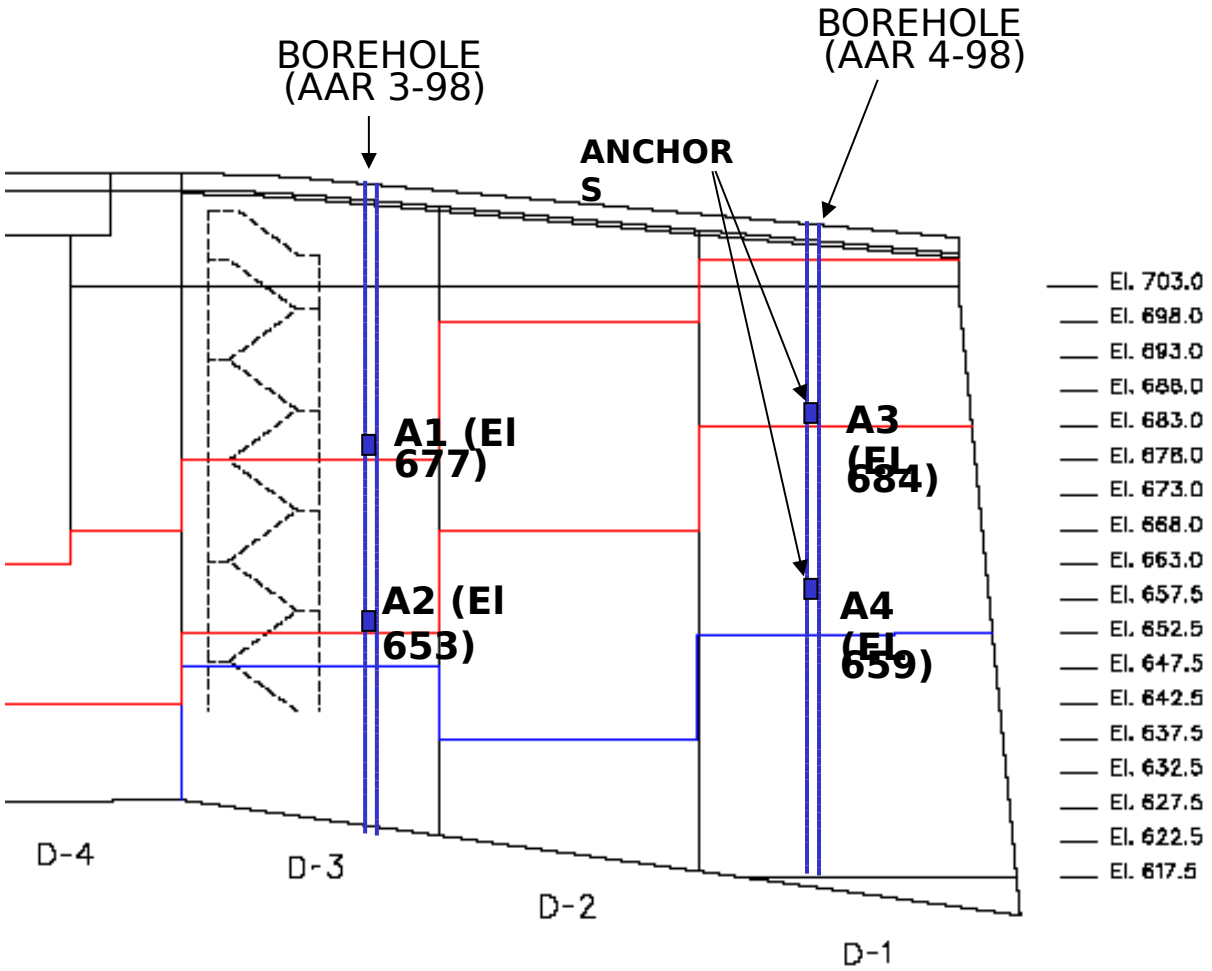
CARTERS REREG DAM BOREHOLE EXTENSOMETERS

22 Jan 2005

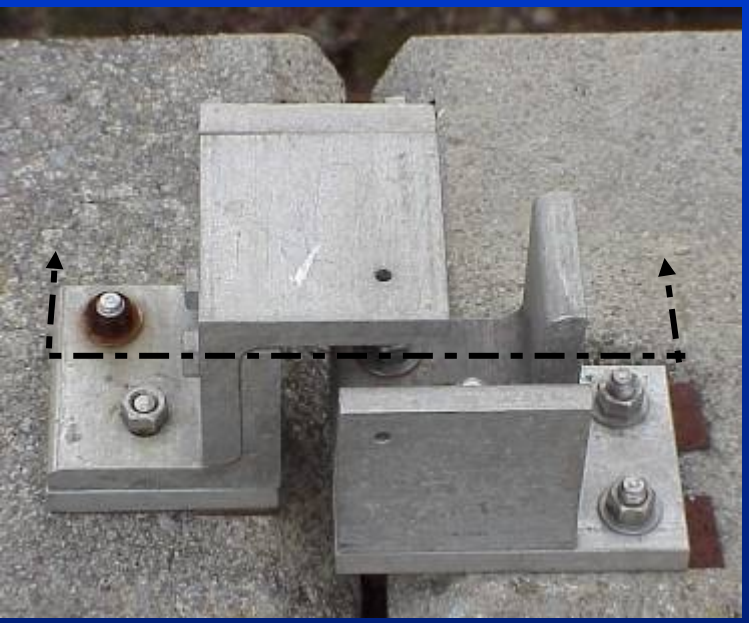
EXTENSOMETER CONCEPT



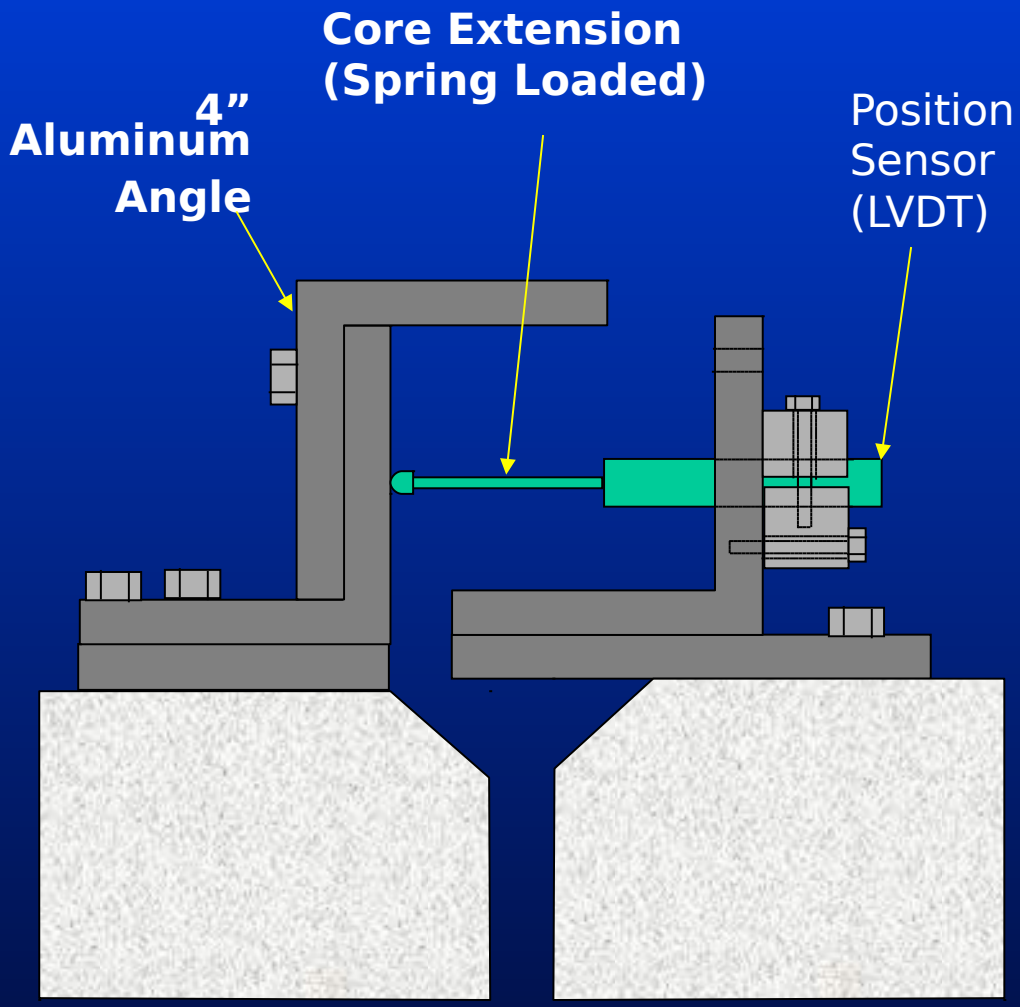
EXTENSOMETER LOCATIONS



Modified RBMD for Automated Displacement Measurement in the Longitudinal Axis



Center Hill Dam - Relative Block Movement Devices (RBMD's)



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LIDAR Survey of the Structure

LEICA Model HDS3000

Stated position accuracy of 6-mm @ 50m

Uses DGPS position tie into state plane

Single point distance accuracy is about 4-mm

Uses proprietary software compatible with most CAD platforms.

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LIDAR survey presented here was conducted by Lowe Engineers, Atlanta, GA

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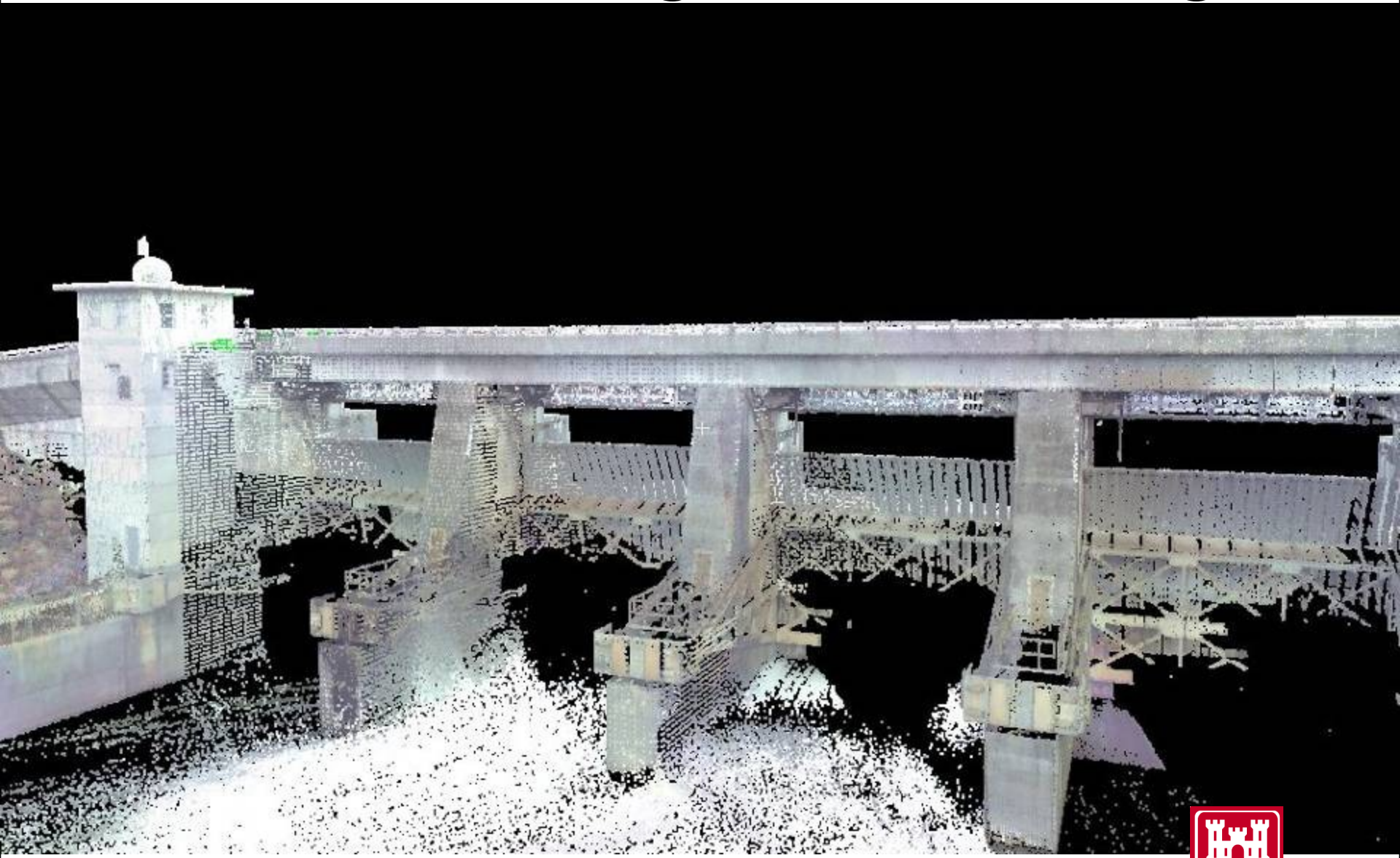
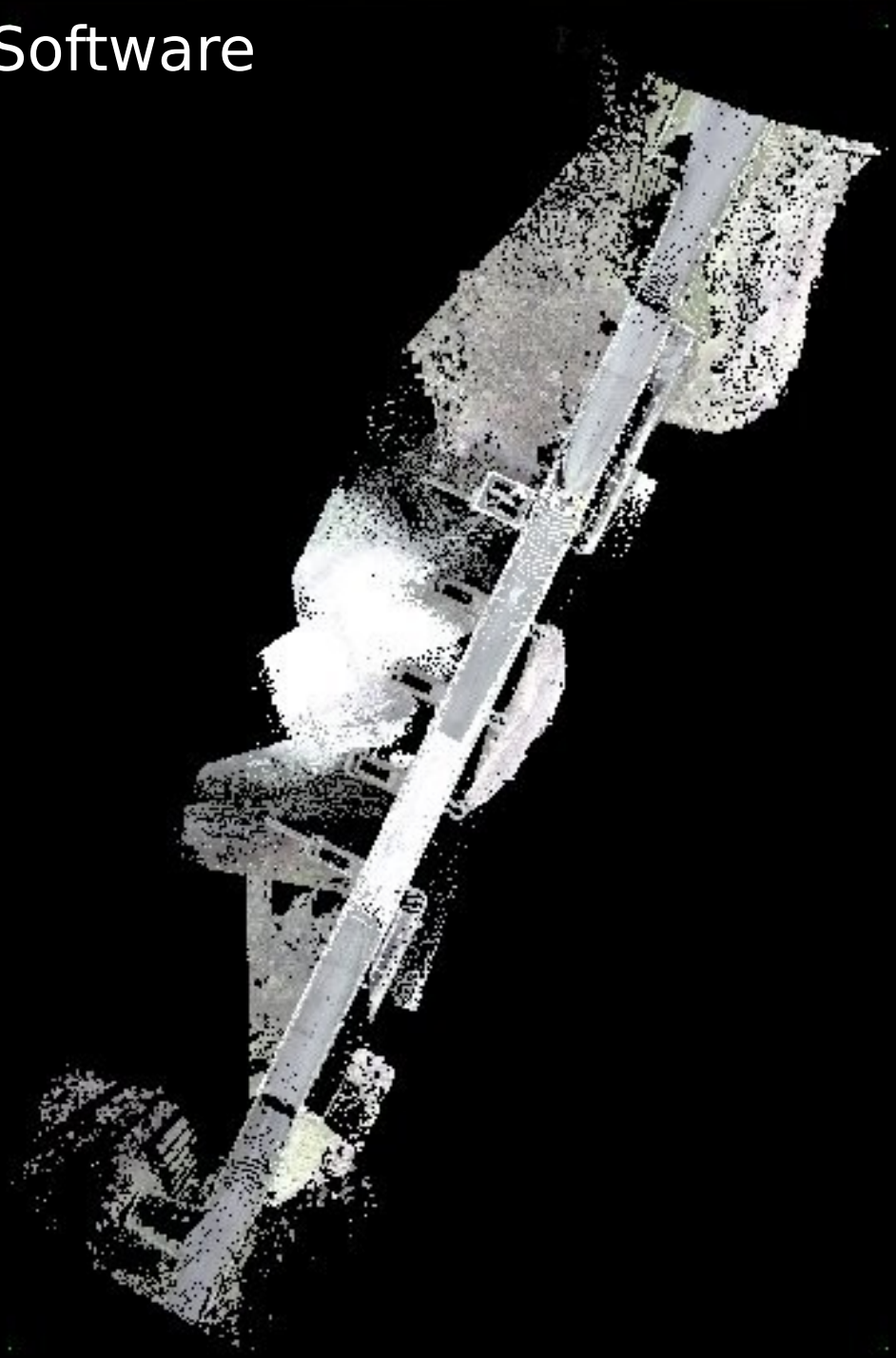
Point cloud rendering of Carters Rereg Dam



Mobile District

CloudWorx Software

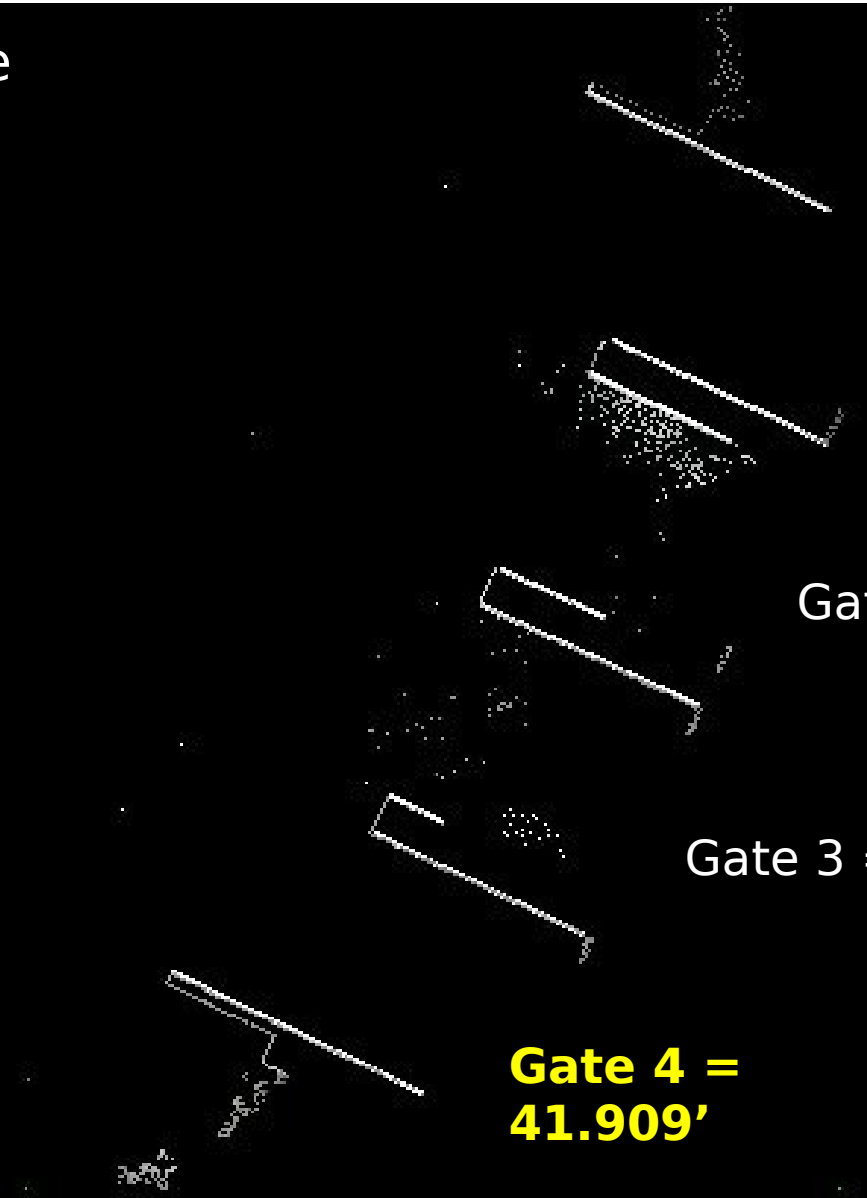
Plan View



Mobile District

Horizontal Slice

Elevation 664-665 (2' above the sill)



Gate 1 = 42.000’

Gate 2 = 42.004’

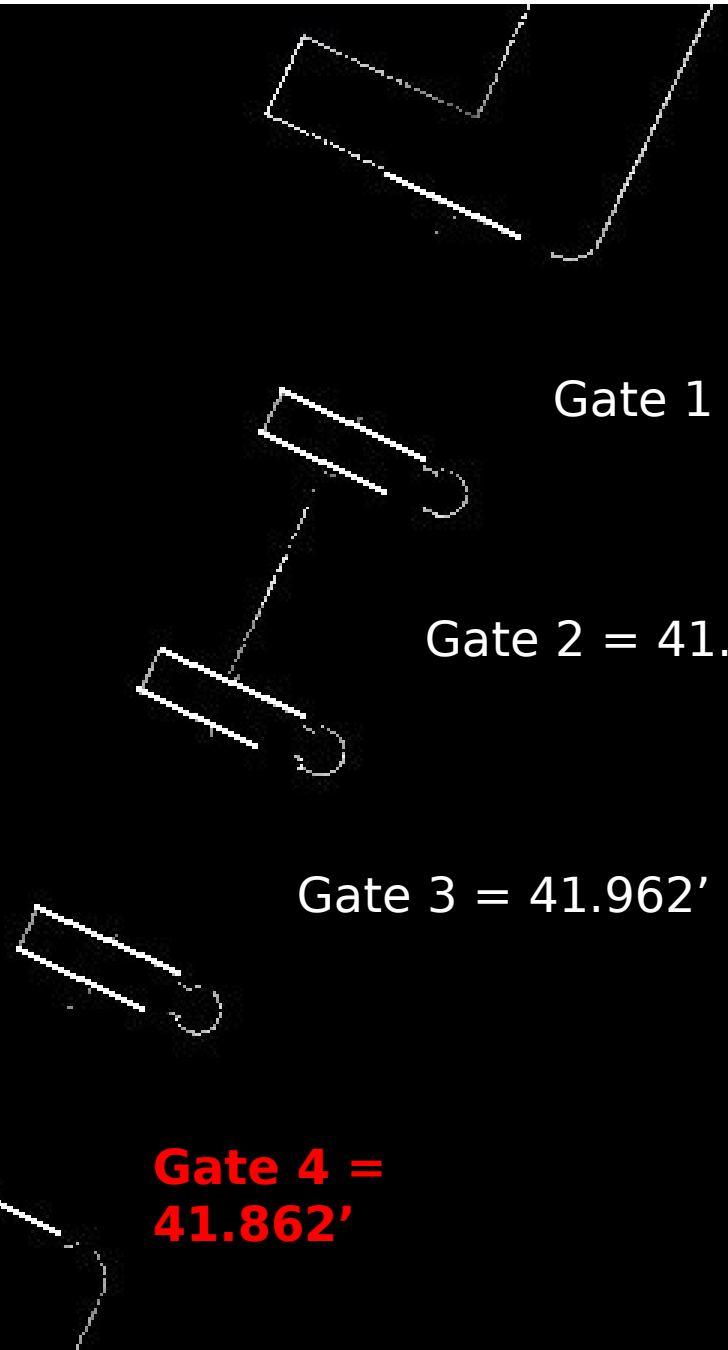
Gate 3 = 42.000’

Gate 4 = 41.909’

Mobile District

Horizontal Slice

Elevation 699-700 (37' above the sill)



Gate 1 = 41.875’

Gate 2 = 41.942’

Gate 3 = 41.962’

Gate 4 = 41.862’

The South Gate Opening was the worst case with a narrowing of almost 3 inches at the pintle level

Advances in Technology for Structural Monitoring Programs

- Fiber optic sensors improve reliability and long term performance
- Robust wireless interfacing and networking reduce hardwire requirements
- Real time access of data through web portals
- Digital Smart-Sensors improve accuracy and simplify maintenance
- Distributed “intelligence” at the sensor automate the decision process and reduce data management

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The future in Long-term Monitoring Instrumentation

Internet Protocol IPv6 will offer enormous potential for remote sensing applications, allowing roughly 100 IP addresses for every person on the planet.

TinyOS has been developed to enable very small, low power, low cost, network linked sensor platforms.

SENSAMETRICS

Wireless Structural Monitoring

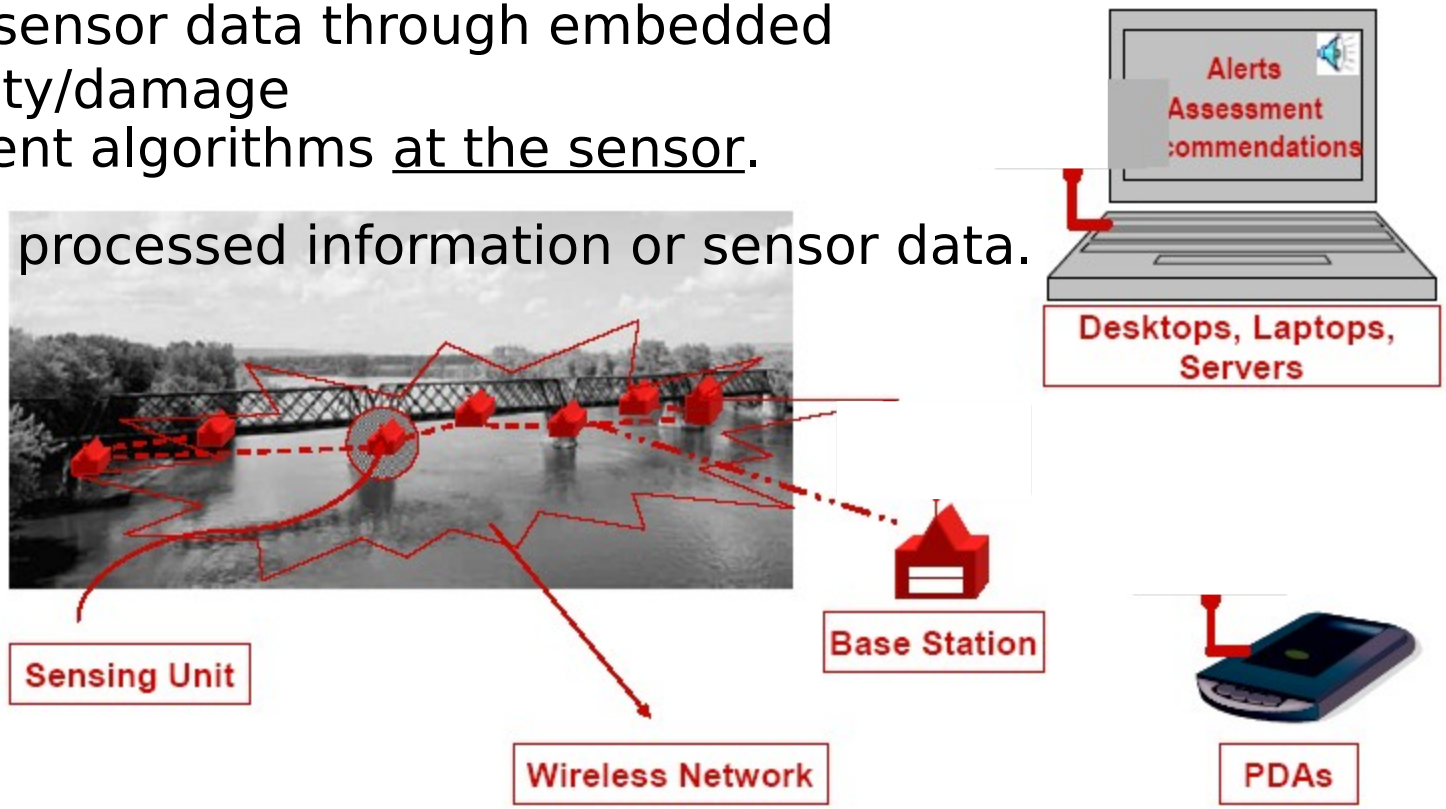
Garo K. Kiremidjian, Founder/CEO

“Sensametrics, Inc. is developing technology for comprehensive and cost-effective solutions for structural monitoring of civil assets – bridges, large facilities, new construction, dams, levee walls and buildings - aimed at identifying the onset, development, location, and severity of structural vulnerability and damage. Sensametrics’ technology concept is based on a *wireless network* of devices, or *sensing units*, for capturing damage/vulnerability information and a *decision support* software environment for information presentation and analysis.”

Sensametrics' Sensing Unit

Each sensing unit has the capability to:

- Interface to multiple sensors (either internal or external).
- Communicate via a wireless mesh network to other units and base.
- Process sensor data through embedded vulnerability/damage assessment algorithms at the sensor.
- Transmit processed information or sensor data.



SENSAMETRICS
Wireless Structural Monitoring

Sensametrics' Sensing Unit

Low-noise 3D accelerometer for ambient vibrations

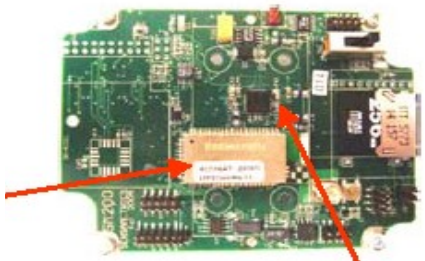
Storage of data and information

Processor for managing the operations of the unit

32 bit RISC CPU for data analysis through embedded algorithms

D size high-density lithium battery

2.4 GHz 802.15.4 radio module with ZigBee mesh networking firmware



3D strong motion accelerometer

Interface to external sensors

Sensametrics' Decision Support Software

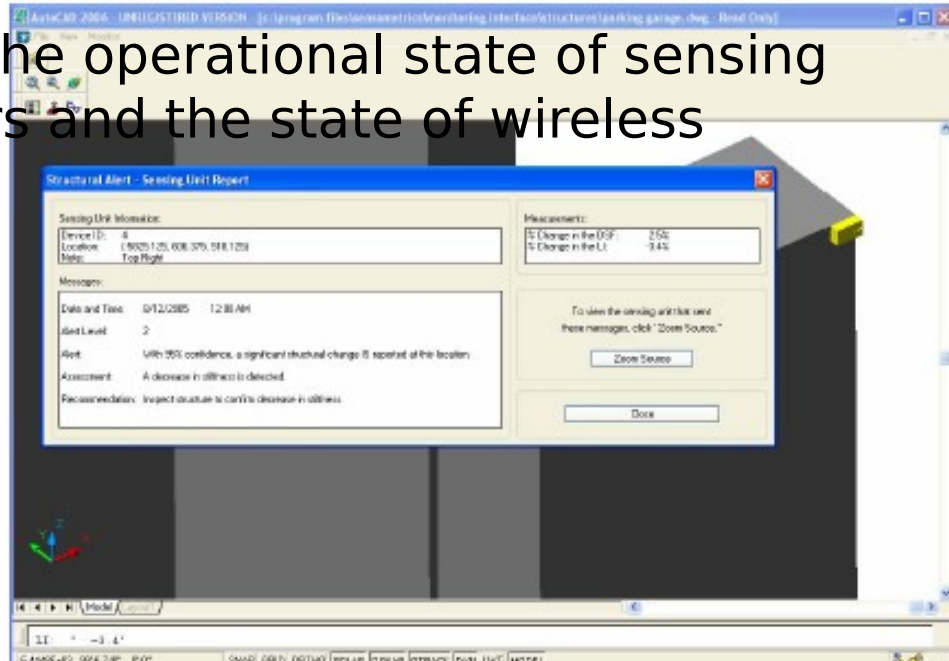
Major functions and outputs to the decision support software include:

(a) interface to the wireless network through command and control messages

(b) Web services so that information can be accessed by desktops, laptops and hand-held devices via the Internet and other networks;

(c) system status indicators on the operational state of sensing units, the condition of sensors and the state of wireless communications;

(d) monitoring data in terms of alerts, damage/vulnerability assessments and corresponding recommendations for action.


Structural Alert - Sensing Unit Report
Sensing Unit Information:
Device ID: 4
Location: (-9925.125, 608.379, 518.125)
Note: Top Right
Measurements:
% Change in the DSF: 2.5%
% Change in the LI: -3.4%
Messages:
Date and Time: 9/12/2005 12:38 AM
Alert Level: 2
Alert: With 95% confidence, a significant structural change IS reported at this location
Assessment: A decrease in stiffness is detected
Recommendation: Inspect structure to confirm decrease in stiffness
To view the sensing unit that sent these messages, click "Zoom Source."
Zoom Source
Done

SENSAMETRICS
Wireless Structural Monitoring

Summary and Conclusions

Permanent installation of sensors and monitoring systems can minimize performance questions.

Maintenance and upgrades to the monitoring systems must be factored into O&M budgets.

Manpower restrictions will force more reliance on technology to “monitor” structural conditions.

Emerging technology will make this possible and more cost effective.

QUESTIONS?

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